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Laboratory Sediment Toxicity Tests, Sediment Chemistry and Distribution of Benthic Macroinvertebrates in Sediments from the Keweenaw Waterway, Michigan

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16. ABSTRACT

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LABORATORY SEDIMENT TOXICITY TESTS, SEDIMENT CHEMISTRY AND DISTRIBUTION OF BENTHIC MACROINVERTEBRATES IN SEDIMENTS FROM THE KEWEENAW WATERWAY, MICHIGAN

K. W. MALUEG,* G. S. SCHUYTEMA, D. F. KRAWCZYK and J. H. GAKSTATTER

U.S. Environmental Protection Agency
Corvallis Environmental Research Laboratory
Corvallis, Oregon 97333

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Abstract — Acute laboratory sediment toxicity tests using the water flea *Daphnia magna* and the burrowing mayfly nymph *Hexagenia limbata* were conducted on sediments from two areas of the Keweenaw Waterway, Michigan, to determine whether the tests reflected the condition of benthic macroinvertebrate communities. The organisms were tested simultaneously in a recirculating bioassay chamber in which *Daphnia* were tested during the first two and last two days of a 10-d *Hexagenia* test. Sediment from the northern, copper-impacted portion of the waterway was generally acutely toxic to *Daphnia*, but not to *Hexagenia*, while sediment from the southern, less-impacted portion was not toxic to either organism. Positive relationships existed between organism mortality, copper content of the sediment and field distribution of macroinvertebrates.

Keywords — Sediment Toxicity tests Benthic macroinvertebrates *Daphnia* *Hexagenia*

INTRODUCTION

Sediments can be contaminated with materials at levels much higher than background that may result in the disruption of the benthic community. Acute sediment toxicity tests have the potential to indicate problems in these contaminated areas. In this report we examine the copper-contaminated sediments of an important waterway and attempt to correlate biological field conditions with chemical and biological laboratory test results.

The Keweenaw Peninsula of Lake Superior, Michigan, once the center of a booming copper mining industry [1], is bisected by the Keweenaw Waterway (Fig. 1). The rich deposits of copper, first discovered in 1843, were mined commercially until 1968 [2]. These mining activities created extensive deposits of copper tailings in and around the area's lakes and rivers. Huge deposits are located at Freda and Redridge, 20 km from the northern entrance of the waterway where, it is estimated, 45 million metric tons of tailings were discharged into Lake Superior [1]. Littoral drift transports the

*To whom correspondence may be addressed.

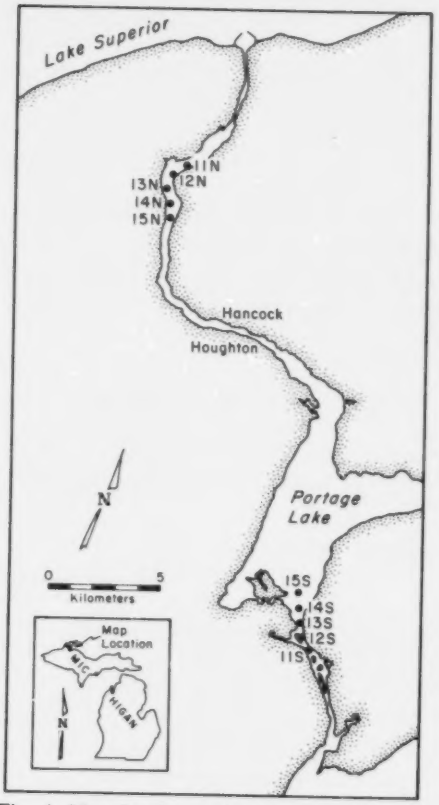

Fig. 1. Map of study area showing northern (N) and southern (S) sampling locations.

copper tailings northeast to the northern entrance of the Keweenaw Waterway, where they enter with Lake Superior water which flushes the system [3]. Extensive deposits of tailings also are located along the waterway in the Hancock-Houghton area and are subject to erosion by the flushing water.

The U.S. Army Corps of Engineers [1] reported that northern waterway sediments contained from 103 to 866 mg/kg Cu, and averaged 425 mg/kg Cu. Lopez and Lee [4] examined the metal composition of bottom sediments in Portage Lake, part of the waterway, and reported values as high as 1,450 mg/kg Cu. Kraft and Sypniewski [5] examined sediments and benthic macroinvertebrates from areas north and south of Portage Lake. They found that the northern sediment averaged 589 mg/kg Cu while the southern sediment averaged 33 mg/kg. Further, they reported fewer numbers and kinds of invertebrates in the northern area compared to the southern.

The purpose of this study was to test the acute toxicity of sediments from the Keweenaw Waterway and to determine the extent to which laboratory toxicity tests results reflected the condition of benthic invertebrate communities. We obtained sediment samples from some of the same Keweenaw Waterway locations that Kraft and Sypniewski [5] studied, and investigated acute lethality, bioassay water chemistry, sediment particle size, sediment chemistry and benthic macroinvertebrate community structure.

METHODS AND MATERIALS

On June 14, 1982, sediment samples were collected by Ponar grab at 10 stations in the Keweenaw Waterway—five to the north and five to the south of Portage Lake (Fig. 1). These sites (11N to 15N in the north and 11S to 15S in the south) had been sampled in a previous study [5]. The stations were at 700-m intervals in midchannel, at an average depth of 10.3 m in the north and 8.8 m in the south. The sediment samples were placed on ice in coolers and shipped to the U.S. Environmental Protection Agency (EPA) Research Laboratory in Corvallis, Oregon, by air, arriving within 36 h. The samples were stored at 5°C until the bioassays were initiated on June 21, 1982.

Three Ponar grab samples also were collected at each site for macroinvertebrates. The sediment was washed through a no. 30 U.S. standard sieve (mesh opening 0.59 mm) and the organisms were handpicked from the debris, preserved in ethanol, identified and counted. The organisms from each sample were dried for several minutes on filter paper and weighed to the nearest milligram. Mollusks were removed from their shells

before weighing. Control sediment was collected from a local Oregon site, Soap Creek Pond No. 7.

Species diversity (H') was calculated according to the Shannon-Weaver expression [6]. The number of species in the top 75% of the population was also calculated (R. C. Swartz, unpublished data).

The laboratory toxicity tests were conducted in triplicate at 20°C in Anderson-Prater type [7] recirculating test apparatus using the water flea *Daphnia magna* and the burrowing mayfly nymph *Hexagenia limbata*. The apparatus consisted, basically, of a rectangular glass chamber positioned over two 4-liter jars. The sediment was placed in the bottom of the glass chamber and water was continually circulated over it. Burrowing mayflies were placed in the sediment while daphnids were placed in a 5.2 cm glass vessel with a screen bottom located in the chamber above the surface of the sediment. Daphnids were ≤ 24 h old; nymphs had a mean length of 2.70 cm (standard deviation 0.38 cm). Details of the apparatus and the test procedures can be found in the report of Malueg et al. [7]. The test sequence was modified as follows. Day 1: Set up apparatus, fill with test water and adjust water flow to 60 ml/min, drain test chamber, add sediment, refill with water with minimal disturbance, let sediment settle. Day 2: Restart water flow, add 20 daphnids to vessel and 5 mayflies to chamber sediment. Day 4: Remove and count daphnids [48-h test (DI)]. Day 10: Add 20 daphnids to vessel. Day 12: Remove and count daphnids [48-h test (DII)], remove and count mayflies (10-d test).

A daphnid toxicity test was therefore conducted during the first two (DI) and last two (DII) days of the 10-d period. The same test water remained in the apparatus for the two tests.

Daphnia magna were obtained from a stock culture maintained at the U.S. EPA Western Fish Toxicology Station, Corvallis, Oregon. *Hexagenia limbata* were collected and shipped from Wisconsin and were not fed during the study. Further information on culturing, collection, feeding and maintenance of test organisms can be found in the report of Malueg et al. [7].

Survival data were pooled for each set of replicates and percent mortality determined. The chi-square test was used to detect differences between control and test survival at the 0.05 level of significance, using a multiple comparison procedure where the α level was divided by the number of nonindependent comparisons to a common control [8].

The test water for the toxicity tests was obtained from the U.S. EPA well near the Willamette River at Corvallis, Oregon. This is relatively soft water, with a hardness (as $CaCO_3$) of less than 30 mg/L. For other parameters, see Table 1.

Sediment grain size was determined according to U.S. EPA methods [9]. Sediment for metal analysis was digested using the acid extraction method of Sinex et al. [10]. Reference soils SO-1 through 4 from the Canadian Certified Reference Materials Project were analyzed concurrently with the sediment samples to verify efficiency of digestion procedures. Metals were subsequently determined using inductively coupled plasma-atomic emission spectrometer (ICPAES) methods as reported by McQuaker et al. [11]. Analysis for sodium, potassium, lead and cadmium, and comparison tests for copper were by atomic absorption spectroscopy using flame or carbon furnace techniques [12]. Samples for aqueous metal analysis were withdrawn from triplicate toxicity test vessels and combined. Soluble copper was defined as that portion remaining in solution after centrifugation at 10,000 rpm for 10 min. Every 10th sample was replicated for ICPAES and atomic absorption analysis. Copper measurements by the ICPAES were compared with measurements by atomic absorption. There was no significant difference between instrumental responses. The copper detection limit was 10 μg/L in water and 1.0 mg/kg in sediment. Total carbon was determined according to

Table 1. Chemistry of initial test water for sediment bioassay experiments[a]

Parameter	mg/L	SD	Range
Ca	6.6	1.1	5.5 - 8.2
Mg	2.0	0.3	1.7 - 2.5
Na	5.2	0.2	5.0 - 5.5
K	0.61	0.04	0.56 - 0.67
Cl	4.8	1.3	3.6 - 7.0
SO_4	1.8	1.1	0.9 - 3.8
Alkalinity ($CaCO_3$)	33[b]	3.5	30 - 38
Hardness ($CaCO_3$)	25[b]	4	21 - 31
Specific conductance	72[c]	10	64 - 89
Al	<0.08[d]		
As	<0.08		
Cd	<0.005		
Cr	<0.01		
Cu	<0.01		
Fe	0.063	0.016	0.041 - 0.085
Mn	<0.01[d]		
Ni	<0.04		
Pb	<0.05		
Sr	0.032	0.006	0.028 - 0.041
V	<0.01		
Zn	<0.01		
NH_3-N	<0.04		
$NO_2 + NO_3$-N	0.24	0.02	0.22 - 0.28
TKN-N	<0.14		
O-PO_4-P	0.034	0.006	0.027 - 0.042
Total PO_4-P	0.035	0.003	0.033 - 0.039

[a]Determinations for four to six sampling dates in 1982, each with replicates.
[b]Calculated.
[c]Specific conductance as μmhos/cm.
[d]These values are detection limits.

Patterson [13]. Total inorganic carbon was determined by a modification of the calcimeter method of Allison and Moodie [14] and a modified direct injection technique of Suzuki et al. [15]. Total organic carbon was determined by difference. All other determinations were by U.S. EPA methods [12].

RESULTS

Toxicity tests

Daphnid mortality for the control sediment was low, ranging from 0% for the first daphnid addition (DI) to 3.3% for the second addition (DII) (Table 2). In DI, sediment from two stations in the north, stations 11 and 12, caused significant mortality, in contrast to the sediment from the southern stations. Mortality averaged 23% for the north versus 3% for the south. In DII, sediment from northern stations 11, 12, 14 and 15 caused high mortality; all were significantly different from the control. The mean mortality for all the northern sampling stations was 78%, as contrasted to 5% for the southern part of the waterway. No significant mortality in DII was associated with sediment from southern stations.

Mortality of *Hexagenia* in the control sediment was 6.7% (Table 3). For the Keweenaw samples the mean mortality was 16% in the north and 8% in the south. Although mortality of *Hexagenia* was higher in sediments from the northern stations than in those from the southern stations, these values were not significantly different from controls.

Dissolved oxygen in the controls averaged 6.0 ± 1.0 mg/L. Mean dissolved oxygen in the test sediment chambers ranged from 6.4 ± 1.0 mg/L for the northern stations to 7.2 ± 0.7 mg/l for the southern stations. Control sediment test pH ranged

Table 2. Comparative toxicity of test sediments to *Daphnia* (48-h test) at beginning and end of 10-d test

Station	DI Survivors/ Total	DI % Mortality	DII Survivors/ Total	DII % Mortality	DI Test vs. control	DII Test vs. control
11N	38/60	36.7	2/60	96.7	+[a]	+
12N	18/60	70.0	0/60	100.0	+	+
13N	58/60	3.3	80/80	0.0	0[b]	0
14N	60/60	0.0	1/60	98.3	0	+
15N	57/60	5.0	4/60	93.3	0	+
15S	58/60	3.3	57/60	5.0	0	0
14S	58/60	3.3	59/60	1.7	0	0
13S	59/60	1.7	56/60	6.7	0	0
12S	60/60	0.0	55/60	8.3	0	0
11S	58/60	3.3	59/60	1.7	0	0
Control	60/60	0.0	58/60	3.3	0	0

[a] + indicates significant difference ($p = 0.05$) in mortality compared to control.
[b] 0 indicates no significant difference in mortality compared to control.
See Methods and Materials for description of DI and DII.

from 6.6 to 7.4. Northern sediment test pH for the same period ranged from 7.0 to 8.0, while the southern ranged from 7.2 to 7.7.

Metal release from sediment during bioassay

Copper was released from the Keweenaw sediment into the bioassay water by desorption and perhaps by the burrowing action of the *Hexagenia*. No detectable copper was present in the control water at the beginning or end of DI. During DII, total copper in the control reached 0.028 mg/L (Fig. 2).

No detectable copper was present at the beginning of DI in either the northern or southern test waters; however, at the end of DI, total copper in the test water ranged from 0.120 mg/L in test vessels containing samples from station 13N to 0.350 mg/L in test vessels containing samples from station 15N. Although additional amounts of copper continued to be released into the water, they were small compared to those of the first 24 h, as were the increases during DII. The range of values at the end of the 10-d period was 0.190 mg/L in 11N samples to 0.510 mg/L in 12N samples.

The same pattern of release was observed in samples from the southern sediments (Fig. 3); however, values were much lower. Only station 11S showed a detectable concentration after DI (0.013 mg/L), and values at the end of the 10-d test ranged from 0.018 to 0.028 mg/L total copper.

Soluble copper concentrations, measured only at the end of DII, were less than 0.010 mg/L in the control and all samples from

Table 3. Comparative toxicity of test sediments to *Hexagenia* (10-d test)

Station	Survivors/Total	% Mortality	Test vs. control
11N	11/14	21.4	0[a]
12N	14/15	6.7	0
13N	10/15	33.3	0
14N	14/14	0.0	0
15N	12/15	20.0	0
15S	13/15	13.3	0
14S	15/15	0.0	0
13S	12/15	20.0	0
12S	15/15	0.0	0
11S	14/15	6.7	0
Control	14/15	6.7	0

[a] 0 indicates no significant difference ($p = 0.05$) in mortality compared to control.

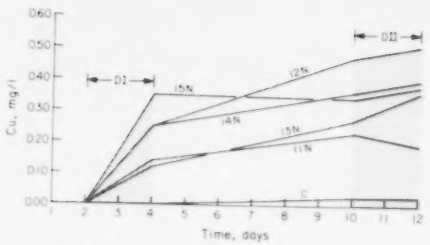

Fig. 2. Total copper concentrations from northern sediment stations during toxicity tests. DI, initial *Daphnia* test; DII, second *Daphnia* test; C, control.

southern stations, while values from the northern sites ranged from 0.011 to 0.052 mg/L. An average 11.6% of the total copper was soluble.

Bulk chemistry

The amount of sediment fines, defined as the percent passing through a no. 230 mesh screen, was much higher in samples from the north than in those from the south, averaging 87.4 and 38.4, respectively. Control sediment averaged 88.5% (Table 4).

Higher total concentrations of metals were present in the north, with stations 14N and 15N showing the highest levels (Table 5). Sediment copper showed the most dramatic differences averaging 612 mg/kg in the north and 24 mg/kg dry sediment in the south.

Total organic carbon levels (%) for sediments tested were 11N, 3.1; 12N, 1.8; 13N, 1.4; 14N, 2.3; 15N, 2.3; 15S, 2.2; 14S, 1.7; 13S, 1.4; 12S, 2.4; 11S, 2.9; and control, 3.7.

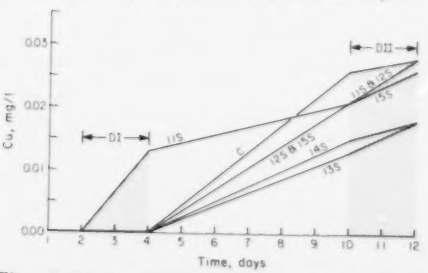

Fig. 3. Total copper concentration from southern sediment stations during toxicity tests. DI, initial *Daphnia* test; DII, second *Daphnia* test; C, control. Note change in scale for copper concentration from that used in Fig. 2.

Macroinvertebrates

Macroinvertebrate populations, number of taxa and biomass were all higher at the southern stations than at the northern (Table 6). Organism numbers averaged 110 per square meter in the north and 491 per square meter in the south, a 4.5-fold difference. There was a mean of 3.8 taxa in the north as compared with 13.4 in the south, a 3.5-fold difference. Differences in biomass, represented by wet weight, were considerable between the northern and southern sites, averaging 0.41 g/m^2 and 3.27 g/m^2, respectively, about an eight-fold difference.

Two measures of diversity, H′ and the number of species in the top 75% of the population, followed the same trends. Mean H′ diversity was only 0.38 in the north, compared with 0.81 in the south. There was a mean of 1.58 species in the top 75% of the population in the north and a mean of 3.40 species in the south.

No Emphemeroptera were collected in the north, but they comprised 36.7% of the organisms in the south (Table 7). Chironomids dominated nearly the entire population (96%) in the north but accounted for less than 25% of organisms in the south. *Hexagenia* was the numerically dominant taxon in the south but was not collected in the north.

DISCUSSION

Our previous laboratory bioassays using the recirculating test apparatus compared results for *Daphnia magna* alone and with *Hexagenia limbata* [7]. We concluded that the tests were more sensitive when the two species were used together, although, in the 5-d test, mayfly mortality was significantly different from the control only when the sediments were highly contaminated. We still believe this to be true. Repeated chemical analysis of the overlying water in the previous study indicated that some of the chemical components were still increasing near the end of the tests. This indicated that

Table 4. Sediment grain size analysis

Station	Mean % retained on mesh size[a]				Mean % passed (mesh 230)
	10	20	60	230	
11N	1.8 ± 2.8	0.6 ± 0.9	5.9 ± 0.7	12.3 ± 1.4	79.3 ± 3.2
12N	2.6 ± 2.9	1.5 ± 1.6	2.4 ± 0.6	11.1 ± 0.8	82.5 ± 5.7
13N	0.3 ± 0.6	0.6 ± 0.6	2.9 ± 0.3	4.4 ± 0.9	91.8 ± 1.1
14N	3.3 ± 2.9	2.5 ± 2.7	0.2 ± 0.4	4.2 ± 0.3	89.7 ± 1.3
15N	2.2 ± 3.3	1.4 ± 2.4	0.2 ± 0.4	2.4 ± 0.6	93.8 ± 3.3
15S	0.8 ± 1.4	6.0 ± 1.0	2.9 ± 1.1	23.9 ± 1.7	66.3 ± 2.3
14S	4.3 ± 1.0	3.4 ± 1.8	7.4 ± 0.2	34.0 ± 1.1	50.8 ± 1.7
13S	16.3 ± 1.3	11.9 ± 2.9	44.9 ± 0.8	18.1 ± 1.5	8.8 ± 3.7
12S	5.1 ± 1.3	4.3 ± 3.9	11.7 ± 0.5	35.0 ± 1.2	44.0 ± 5.0
11S	4.2 ± 3.7	6.4 ± 1.4	21.0 ± 0.5	46.5 ± 0.8	22.0 ± 5.6
Control	—	1.0 ± 0.6	0.6 ± 0.8	9.9 ± 2.1	88.5 ± 2.4

[a]U.S. standard.

a more sensitive 48-h daphnid response might be expected if they were tested later in the sequence of a mayfly test. We therefore conducted a 10-d test with the Keweenaw sediments and compared two 48-h daphnid tests, at the beginning and at the end of the test sequence. Presumably, if additional chemicals were released, greater mortality of the daphnids would occur in DII. We did, in fact, demonstrate this. Mortalities were higher and there were more instances of significant differences between control and test mortality in the DII tests as compared with the DI tests.

In sediment from all northern stations except 13N there was high mortality of

Table 5. Bulk sediment analysis

Station	Cd	Cr	Cu	Hg	Ni	Pb	V	Zn
mg/kg dry weight basis								
11N	1.8	88	480	0.10	89	22	120	130
12N	1.3	97	650	0.20	97	25	140	130
13N	1.1	73	140	0.10	63	17	110	100
14N	1.5	120	860	0.20	120	29	170	240
15N	2.0	130	930	0.30	130	40	180	170
15S	0.7	51	37	0.30	34	27	64	91
14S	0.5	32	19	0.06	30	7.7	40	58
13S	0.2	16	13	0.20	29	2.1	21	37
12S	0.5	28	34	0.10	28	8.7	34	72
11S	0.5	18	15	0.01	24	1.9	22	53
Control	2.5	300	200	0.06	120	21	390	150

	Al	Ca	Fe	K	Mg	Mn	Na
% dry weight basis							
11N	2.10	1.20	4.00	0.34	1.30	0.061	0.04
12N	2.60	1.30	4.10	0.42	1.50	0.077	0.04
13N	1.80	1.50	3.10	0.40	1.50	0.050	0.05
14N	2.90	1.60	4.00	0.49	2.00	0.081	0.05
15N	2.90	1.60	5.90	0.40	2.20	0.087	0.05
15S	1.50	0.39	2.00	0.34	0.16	0.033	0.03
14S	0.88	0.26	1.40	0.19	0.35	0.023	0.03
13S	0.36	0.25	0.67	0.07	0.21	0.011	0.02
12S	0.74	0.23	1.30	0.16	0.32	0.020	0.03
11S	0.46	0.17	0.81	0.09	0.18	0.014	0.02
Control	7.30	0.83	9.50	0.08	1.50	0.180	0.08

Table 6. Macroinvertebrate analysis

	Community structure					Composition	
				Diversity[a]			
Station	No./m²	No. taxa	Biomass (g/m² wet wt)	H'	Species in top 75%	% Emphemeroptera	Numerically dominant taxa
11N	127	5	0.24	0.62	2.69	0.0	*Procladius*
12N	79	4	0.33	0.49	1.75	0.0	*Chironomus*
13N	6	1	0.00	0.00	0.75	0.0	*Procladius*
14N	170	6	0.68	0.53	1.80	0.0	*Stictochironomus*
15N	170	3	0.80	0.26	0.91	0.0	*Chironomus*
15S	430	11	3.12	0.87	3.86	12.7	*Chaoborus*
14S	424	12	3.11	0.85	4.19	37.1	*Tanytarus*
13S	218	11	1.05	0.80	3.50	36.1	*Hexagenia*
12S	818	17	3.28	0.69	1.98	53.3	*Hexagenia*
11S	564	16	5.78	0.83	3.45	44.1	*Hexagenia*

[a]Does not include unindentified forms.

daphnids in DII. In sediment from all northern stations except 13N there was high mortality of daphnids in DII. Although the bulk chemical analysis for 13N shows relatively low copper values for this station, a considerable amount of total copper was present in the test water. We cannot explain this anomaly.

We also have no explanation for the high levels of metals in the bulk sediment of the control (Table 5). Soap Creek Pond No. 7, one of a series of research ponds created 25 years ago, is located 12 km north of Corvallis on land owned by Oregon State University. No point or nonpoint pollution source exists in this controlled-access area. Records indicate no addition of metals to the pond. We analyzed soil samples taken 20 m from the pond and obtained similarly high values. The extremely low mortality data from control sediments, however, show these potential contaminants do not become available in our test sequence.

Although our tests were not designed to show cause and effect relationships, the data suggest that daphnid mortality and the reduction in field macroinvertebrate fauna in the north was, in fact, due to copper. The lack of significant mortality in laboratory *Hexagenia* tested in the northern sediments did not correlate with the absence of native *Hexagenia* from that region. The 10-d laboratory test, however, is designed only to indicate acute toxicity and would not detect subtle long-term effects. It is conceivable that the absence of burrowing mayflies in the northern part of the waterway could be related to an inability of the organisms to complete their life cycles and maintain viable populations. Kraft and

Table 7. Percent benthic macroinvertebrates from test sites

Station	Ephemeroptera	Chironomidae	Amphipoda	Mollusca	Oligochaeta	Others
11N	0.0	95.2	0.0	0.0	0.0	4.8
12N	0.0	84.6	0.0	0.0	0.0	15.4
13N	0.0	100.0	0.0	0.0	0.0	0.0
14N	0.0	100.0	0.0	0.0	0.0	0.0
15N	0.0	100.0	0.0	0.0	0.0	0.0
15S	12.7	>4.9	0.0	1.4	5.6	25.3
14S	37.1	22.9	12.8	2.8	11.4	12.8
13S	36.1	16.7	8.3	2.8	27.8	8.3
12S	51.8	8.1	23.7	1.5	7.4	7.4
11S	44.1	9.7	13.9	4.3	18.3	9.7

Sypniewski [5] suggested that copper was responsible for the absence of mayflies in the north and concluded that sediment particle size was not responsible for the reduced fauna. Kraft [16] also concluded that copper tailings were responsible for eliminating the amphipod *Pontoporeia hoyi* from an area in Lake Superior near the entrance to the Keweenaw Waterway.

Gannon and Beeton [17] used native *Pontoporeia* in sediment selectivity and viability tests and concluded that the tests had relevance to the Great Lakes because of the native organisms. It is interesting to speculate, however, about the relationship between the *Hexagenia* used in our laboratory tests (which were collected from unpolluted sites) and the *Hexagenia* found in the southern portion of the Keweenaw Waterway. The test *Hexagenia* were not sensitive enough to show significant mortality. Native *Hexagenia*, which may be more tolerant to copper, would probably have given similar results. Brown [18] showed the isopod *Acellus meridianus* from polluted sites to be more tolerant to metals than the same species from unpolluted systems. Similarly, Wentsel et al. [19] presented data showing evidence of resistance to metals in chironomid larvae from contaminated sites.

The recirculating test apparatus described is a good device in which to conduct sediment bioassays on a routine basis. We continue to support the use of *Daphnia magna* as a surrogate species for benthic invertebrates in the sediment bioassay. Its sensitivity is greater than that of other organisms tested. The *D. magna* mortality correlates with major disruptions in the benthic community.

The field assessment from the Keweenaw Waterway does correlate with laboratory bioassay results, showing ecological relevance and indicating that laboratory toxicity tests may be used to determine potential problems due to toxicant buildup in sediments.

CONCLUSIONS

The following conclusions can be drawn from the results of this study:

1. There was a positive relationship between sediment–water contact time and toxicity in this type of acute test.
2. Sediment from the Keweenaw Waterway in Michigan was acutely toxic to *Daphnia magna* at four of the five sampling sites studied north of Portage Lake. Sediment from none of these sites was toxic to *Hexagenia limbata*.
3. Sediment from the Keweenaw Waterway at all five sampling sites south of Portage Lake was not acutely toxic to either daphnids or burrowing mayflies.
4. The significant quantities of total and dissolved copper present in the test water of northern sediments at the conclusion of the bioassay tests suggest that copper contributed to the mortality of the daphnids.
5. Positive relationships exist between daphnid laboratory bioassay data and the field distribution of benthic organisms.
6. The use of *Daphnia magna* in the sediment bioassay as a surrogate species is supported.

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